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Research on key technologies of train-way-side communication loop modulation and antenna

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ABSTRACT

China has a vast territory and a large population, so rail transit has always been an important direction of China's development. With the continuous development of rail transit in China, higher requirements put forward for the efficiency, safety and stability of train operation. The train and wayside communication system is an important part of train control system. Only by using reliable communication technology and realizing information exchange between train and ground, can the continuity, safety and real-time of train operation control be realized. In this paper, the train and wayside communication system is taken as the research object, the 2FSK modulation technology of the loop signal and the key technology of antenna are deeply analyzed and studied, the train and wayside communication simulation system is constructed. The vehicle-ground communication loop is laid on the ground. The vehicle-ground communication system transmits the ground information to the cross-loop in the mode of modulating the 2FSK signal. The carrier antenna senses and receives the ground loop information, identifies and judges the modulation information sent by the ground loop through the information demodulation equipment, demodulates the information sent by the ground, realizes the train and wayside communication and constructs the laboratory debugging system. The system basically realizes the established functions.

Keywords: Train and wayside communication system; Train and wayside communication loop; modulation; CBTC system; FSK; wireless transmission

1. INTRODUCTION

In order to improve China's development level and promote continuous economic progress, urbanization is an inevitable choice for development. Therefore, the urban population will increase in the future, and one of the problems that come with it is how to effectively solve the problem of traffic congestion [1]. For the sake of people's travel, rail transit has been booming at home and abroad. Compared with traditional transportation tools, rail transit has many advantages, including low energy consumption, high environmental protection, high system reliability, less pollution, convenient travel, strong transportation capacity and fast transportation speed [2].

Rail transit is an important public infrastructure for the benefit of the country and the people. It is also the way for most people to choose to travel. It plays an irreplaceable role and significance in the field of transportation [3]. The development of rail transit not only facilitates people's lives, but also drives the development of related industries and promotes economic growth along the route. As of December 31, 2017, China has opened 35 urban rapid urban rail transit lines with a total length of 4823.1km and a total of 157 working routes. Today, the control systems used in typical rail transit are train control systems that integrate vehicle-to-ground communication systems [4]. The CBTC system was first proposed by foreign scholars in the 1960s. It carried out systematic research and phased in the early 1980s and officially began its field trials in the 1990s. As a development and upgrade of the traditional train control system, the CBTC system has many excellent performances that were not available in traditional control technologies and systems [5]. It is mainly reflected in high safety performance, strong control performance, and more precise and rich functions. In practical applications, CBTC can achieve shorter operating intervals while ensuring safe operation of the train. The CBTC system has become the main development direction of the world urban rail transit train operation control system. With the rapid development of information technology and communication technology, more and more vehicles in the CBTC system are directly adopting wireless communication. The use of wireless communication for communication between vehicles and vehicles can greatly improve the performance of the entire train control system. To achieve a more efficient, faster and more reliable rail transit system [6].

Currently, urban rail transit train control systems use communication-based train control (CBTC). The CBTC system was first proposed by foreign scholars in the 1960s. In the early 1980s, it began systematic research and phased testing, and officially began

to enter the field experimental phase in the 1990s. Compared with other traditional train control systems, this new CBTC system has a series of incomparable advantages [7]. Through the CBTC system, the ground control system can control the train more accurately and provide more safe operation for the train. It allows for shorter operating intervals while ensuring safe operation of the train. The CBTC system has become the main development direction of the world urban rail transit train operation control system [8].

When building a subway in China, vehicle communication technology will be established in the passenger information system. In the early days of subway construction, vehicular communication technology still used WLAN (Wireless Local Area Network) technology. However, due to the immature technology, there are some problems with subway vehicle communication technology. The use of wireless vehicle-to-ground communication has gradually become an important means of rail transit signal systems. In the CBTC system, vehicle-to-ground information exchange uses a large number of wireless communication methods [9]. The communication quality of the core equipment is especially important for the reliable operation of the signal system. Therefore, this paper focuses on the communication modulation technology between vehicles and terrestrial systems.

The track circuit also needs to undertake the task of vehicle-to-ground communication in the conventional traffic control system that is, the signal transmitting and receiving device is installed at the joint of each part of the track, in which the track of the train is used as a medium for signal transmission [10]. The specific communication process is to obtain train travel information by transmitting signals of different frequencies on the train through the track circuit. The biggest advantage of this method is good reliability and low cost, so it is superior in terms of cost performance. However, with the continuous development of the rail transit industry, this traditional communication system is very unsuitable for construction of a modern vehicle-to-ground communication system [11].

Galileo Marconi became the first wireless communication system in the UK after inventing radio communication in 1897, mainly for continuous communication between mobile vessels. Since then, wireless communication technologies have been widely promoted and applied in various disciplines. In the rail transit industry, radio technology has also been widely adopted, and wireless technology has been greatly developed in vehicle-to-ground communication systems [12]. By integrating the wireless communication technology into the train control system of the rail transit, the vehicle-to-vehicle-to-ground information transmission is performed by wireless communication, and the control operation for the train traveling state can be realized by the two-way communication. At present, many countries around the world have developed their own vehicle-to-ground communication systems using wireless communication technology. Among them, the United States conducted research on wireless vehicle communication technology as early as the 1980s, and tried to apply it in the actual rail transit control system. Japan is another country with early research experience in the field of wireless communications. Therefore, Japan's rail transit communication system also has high advanced technology, and there are many advanced achievements in wireless vehicle communication systems. Although the United States and Japan have rich research results in the field of rail transit wireless communications, due to many reasons such as practical applications, these two countries have not been able to implement wireless communication technology in the actual rail transit system, and are still in trial stage. For European countries, because the communication standards and communication technologies used by rail transit systems in different countries are different, it is difficult to unify, so when the train crosses the border, it is impossible to communicate with each other [13].

The research of CBTC system actually started in China. Wang Xishi of China first proposed the concept of CBTC system in 1936. However, due to factors such as the limitations of the real environment and technical conditions, the follow-up work is mainly on the theoretical direction. Afterwards, with the research of CBTC in foreign academic circles and transportation fields, China has further studied the theory and model of CBTC based on the research results and typical management of the State Grid, and achieved certain results in the simulation of CBTC system using computer. The research results, published the "Application of Wireless Data Transmission in Railway Safety" report was published at the 2000 China Railway Society Annual Meeting. In this report, for the GSM-R technology, the feasibility of wireless data transmission in rail transit is analyzed, and then domestic universities and many scholars have conducted a wave of research on the CBTC system [14].

There are also researchers in China who have analyzed the impact of wireless communication protocols on the safety of train control systems in the study of vehicle-to-ground communication systems. The secure communication protocol is typically added to the application layer in the Open System Interface (OSI) protocol of the communication system. Domestic scholars focus on the security information transmission process through non-secure design communication security related systems, as well as related system security design issues. Some researchers have proposed a secure communication protocol verification method that combines model verification and simulation for the characteristics of a secure communication protocol for train control systems. The functionality and performance of the secure communication protocol is verified by using a colored Petri net. Some scholars have proposed a method for predicting the security of communication system information transmission using software tools. This method

mainly uses OPNET tools to simulate the data transmission process of CBTC and the security of the communication protocol in the process. In general, the most important function of the secure communication protocol in the train control system is that when the communication system itself is subject to external attacks, the security protocol can ensure that the confidentiality and authenticity of the communication system are not problematic, and at the same time ensure the safety of the train control system. In actual communication system design and optimization, the parameters and operations of the secure communication protocol are generally not involved because in general the secure communication protocol is established between the application layer and the communication layer [15]. In the design of vehicle-to-vehicle communication system, it is necessary to focus on the verification process of the secure communication protocol. On the other hand, most of the research on the communication security of rail transit systems is mainly focused on the parameter design of the physical layer of the communication system. Therefore, the signal strength received by the receiving terminal and the signal noise of the signal are usually selected in the design. The QOS indications of the transport layer and the application layer of the vehicle-to-ground communication system are not studied as a performance indicator and lack of a specific wireless communication technology (GSM-R, WLAN or LTE-M combination).

2. FSK SIGNAL MODULATION TECHNOLOGY

FSK application principle

Digital frequency modulation is also known as frequency shift keying (FSK). In digital frequency technology, advanced carrier frequencies can be used to transmit and receive digital information. The technique of modulating using two frequencies is also called 2FSK. When modulating using the 2FSK technique, the carrier frequency of the signal is described using two symbols, 0 and 1. The two symbols are used to correspond to carrier signals representing two different frequencies [16]. The frequencies of the two carrier signals are denoted by f_1 and f_2 , respectively. In general, the description of 2FSK modulation is expressed by the following formula:

$$e_{2FSK}(t) = \begin{cases} A\cos(\omega_t + \Phi_n) \\ A\cos(\omega_t + \theta_n) \end{cases}$$

According to the mathematical principle, the carrier signal of the above two different frequencies can be regarded as a superposition between the two signals, so the above formula can be expressed as:

$$\left[\sum_n \bar{a}_n g(t - nT_s) \right] \cos(\omega_2 t + \Phi_n)$$

The 2FSK modulation process is mainly divided into two parts, the first part is modulation and the other part is demodulation. The process of modulation is to send a binary digital sequence with two sets of carriers of different frequencies. In a specific transmission process, 1 may be used to correspond to the carrier frequency w_1 , and 0 is used to correspond to the carrier frequency w_2 in the modulation process. As shown in Fig.1, the modulation principle of 2FSK is expressed, and two mutually independent signal sources w_1 and w_2 can be selected by a switching circuit controlled by a rectangular pulse sequence [17].

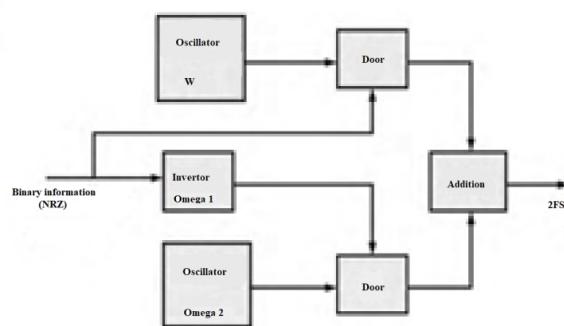


Figure 1 (2FSK) modulation principle

Another demodulation process, first for the 2FSK modulation technique, is mainly divided into two modes of demodulation processes, namely a coherent demodulation method and a non-coherent demodulation method. Generally, in the actual train communication system, the demodulation method of the signal mostly adopts the demodulation technology, so the demodulation process of this mode is mainly introduced here. The signal is sent by a moving train and then modulated by two carrier signals of different frequencies. The carrier frequencies of the two modulated signals are represented by w_1 and w_2 , respectively. The

demodulation process first uses two band pass to filter the two carrier modulated signals and then separates the two signals, with the two filters being selected arbitrarily. Then, the two modulated signals obtained after the separation are filtered again. Finally, the filtered two signals are respectively multiplied by the carrier signal to complete the process of deciphering demodulation, and then the carrier obtained by the product operation is sampled by using a low-pass filter and a sample determiner. The output principle is shown in Fig.2.

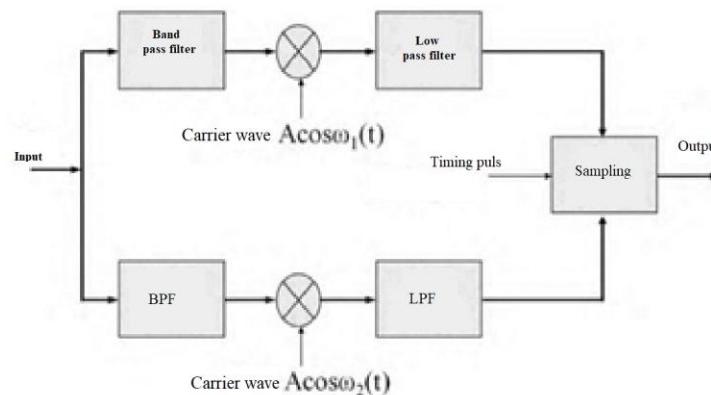


Figure 2 FSK coherent demodulation principles

Due to the many train signal transmission equipment and many waveform systems, the 2FSK modulated signal is used to maintain the edge frequency accuracy. In order to further improve the accuracy of the train signal transmission, it is necessary to ensure the continuity of the signal phase and the waveform conversion. This is because the continuous phase can be modulated by the low frequency signal, which is advantageous for controlling the switching of the upper and lower frequencies. The 2FSK signal is a phase modulation method that also maintains continuous waveform conversion.

In the specific application, it is also necessary to consider the influence of the actual waveform generated by the device and the time domain waveform. The transmission signal generated by the 2FSK signal in the time domain is a sinusoidal signal. However, in the actual communication, a programmable counter is used to generate signals of different frequencies for conversion of the signal, but the signal generated by the counter is in the form of a square wave. Therefore, the signal is required to ensure a converted waveform with a higher precision. When the signal of the train is converted by 2FSK modulation, the converted signal is filtered by the low-pass circuit, and finally the high-frequency harmonic frequency in the signal is filtered according to the Fourier variation from the time domain to the frequency domain. In addition, the main frequency of the signal is kept constant, but the accuracy of this operation is low. In order to better convert the square wave into a sine wave, it is possible to optimize the processing of the train signal by means of energy storage, switching, operational amplifier isolation and amplification capacitors by means of various electronic devices, thereby improving the signal between the vehicle and the ground transmission.

Modulation and transmission of loop information

A typical ATO loop structure diagram is shown in Figure 3. In the communication system as shown, the direction of communication of signals between the vehicle and the ground is unidirectional, so this is a one-way transmission communication system mode. In the specific signal transmission, the ground control system is first used as the signal source to transmit the information. The signal transmission can adopt two different viewpoint frequencies, which are 36.9 kHz and 35.1 kHz, respectively. The signal transmission rate in this system can be kept at 1200 baud.

The ground control system modulates the signal by SFSK with a specific unit and then sends the signal serially to the ATO loop. The on-board communication device on the train can acquire the modulated signal on the ATO loop as the train travels through the loop. After collecting the modulated signal, these in-vehicle devices can demodulate the signal according to the demodulation principle and restore the information that needs to be transmitted. The transmitted information mainly includes the important key train information such as the position and running state of the train. Then the control system in the train compares and analyzes the geographical location information obtained by the ATO loop with the location information stored on the train, so as to timely update the driving position information of the train. In practical applications, the distance between every two intersections in the loop is fixed, and the in-vehicle information on the train stores the position information of these intersections in advance, so that

when the train passes near the intersection, the vehicle communication device can quickly collect data and analyze the real-time position information of the current train in the calculation [18].

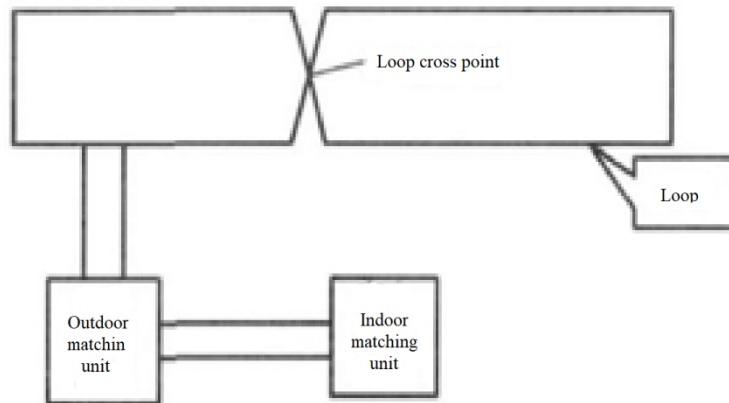


Figure 3 ATO loop structure principle

Loop information demodulation equipment structure and principle

Fig.4 is a schematic diagram showing the working principle of the loop information demodulating device. The loop information demodulation device needs to demodulate the 2FSK signal sent by the ground ATO loop, acquire the serial communication information sent by the ground, and obtain accurate positioning information by identifying the intersection of the loop. During the entire design process, external wireless receiving equipment should be considered to introduce interference, and effective filtering measures should be taken for known interference sources to minimize the amplitude of the interference signal.

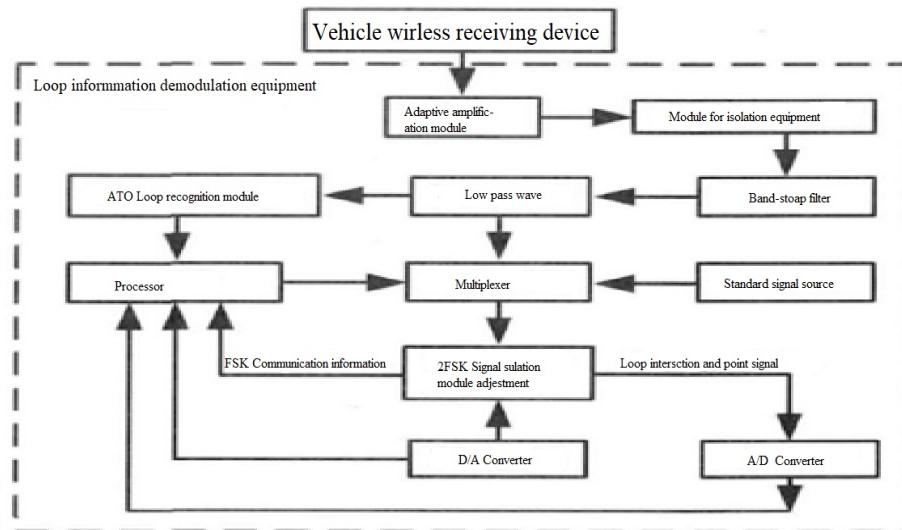


Figure 4 Block diagram of the loop information demodulation device

Signal amplification

The vehicle wireless receiving device can completely receive the cyclic signal, and the received signal includes a track code cycle signal. When the train is running, the vehicle receiving device will vibrate up and down together with the train, and the distance between the in-vehicle wireless receiving device and the ground ATO loop will be variable and the amplitude of the received signal will also change. This requires the signal to exhibit adaptive amplification. During the train entering the ATO loop, the signal strength continuously changes, and the train travels as short as possible, and the train crosses the critical section and reaches a steady state. The mathematical expression of the signal adaptive amplification module in this scheme is:

$$V_{out} = V_{in} e^{-\frac{\sqrt{2}}{8} av_{out}}$$

The parameter a in the above formula represents the feedback coefficient. According to the formula, since the parameter and the output voltage are exponential, if the feedback system becomes smaller, the system output voltage will change significantly. According to the above function, the relationship between V_{out} and V_{in} can be simulated by the simulation software to obtain the curve shown in Fig 5. By further variation, the sweet potato relationship between the voltage gains (GAIN) and V_{in} can be obtained as shown in the simulation results. According to the function curves in Figs. 5 and 6, it can be analyzed that the voltage gain has little effect on the external signal with small amplitude and cannot attenuate the signal. However, as the amplitude of the external signal increases, the amplifying circuit will attenuate the input signal. By this attenuation, the subsequent signal processing circuit can be effectively protected, and at the same time, the length of the critical region can be reduced.

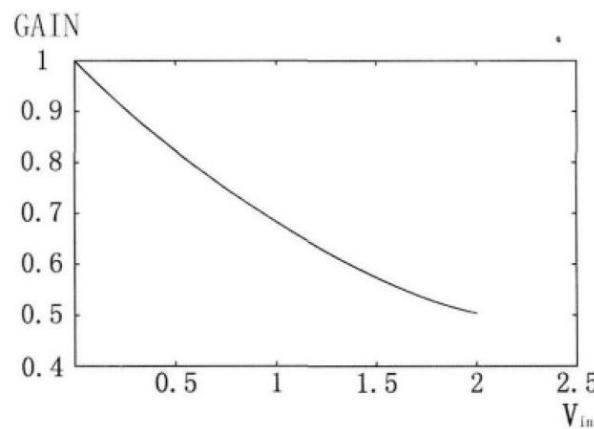


Figure 5 V_{out} and V_{in} relationship

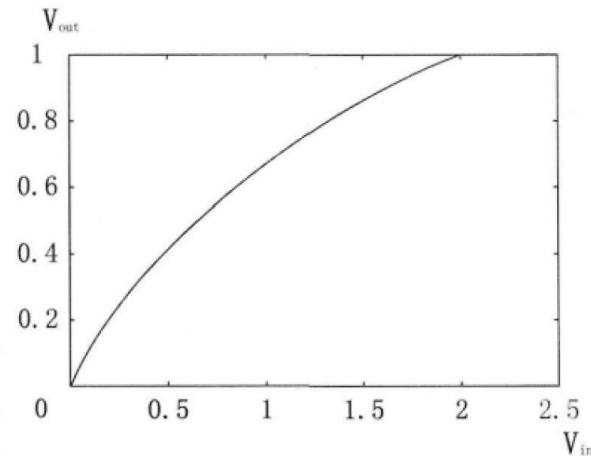


Figure 6 GAIN and V_{in} relationship

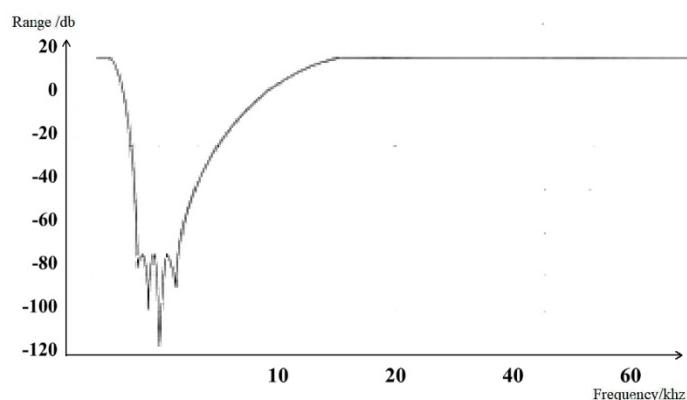


Figure 7 Band-rejection filter simulation wave

Signal Filtering

1. Band stop filter: The in-vehicle wireless receiving device can receive all signals transmitted by the ground, including orbit code signals (4-6 kHz) that can interfere with the cross-loop signals. The band stop filter effectively attenuates the track code signal (-70dB) and amplifies (20dB) the modulated 2FSK signal (36 kHz). Figure 7 shows the amplitude-frequency response simulation waveform of the band-stop filter.
2. Low-pass filter: Filters high-frequency signals with a frequency greater than 2FSK carrier frequency (36 kHz).

Information Demodulation

Demodulation module for 2FSK signals: This scheme uses a phase-locked loop to demodulate 2FSK signals. The phase-locked loop is a phase automatic tracking system that includes a phase detector (PD), a loop filter (LF), and a voltage controlled oscillator. The three basic parts of the (VCO) are shown in Figure 8.

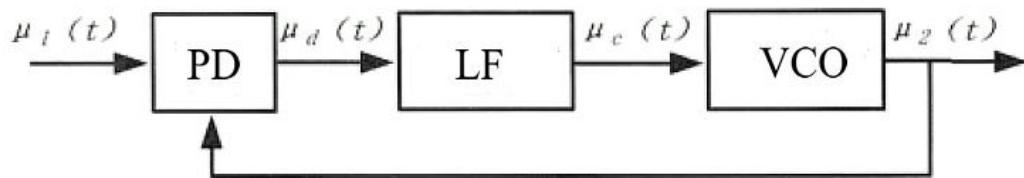


Figure 8 Internal structure of phase-locked loop

The phase-locked loop implements the locking function and has a range of requirements for the amplitude of the input signal. When the amplitude of the collected signal is small enough, the phase locked loop is unlocked. In this scheme, this feature is used to implement loop intersection identification. The determination of the phase-locked loop parameter is directly related to the stability of the 2FSK signal demodulation.

FSK wireless signal demodulation technology application mode

When the train is running on the positive line, the ATO loop for the ground can be divided into A, B, C, and D states as shown in Figure 9.

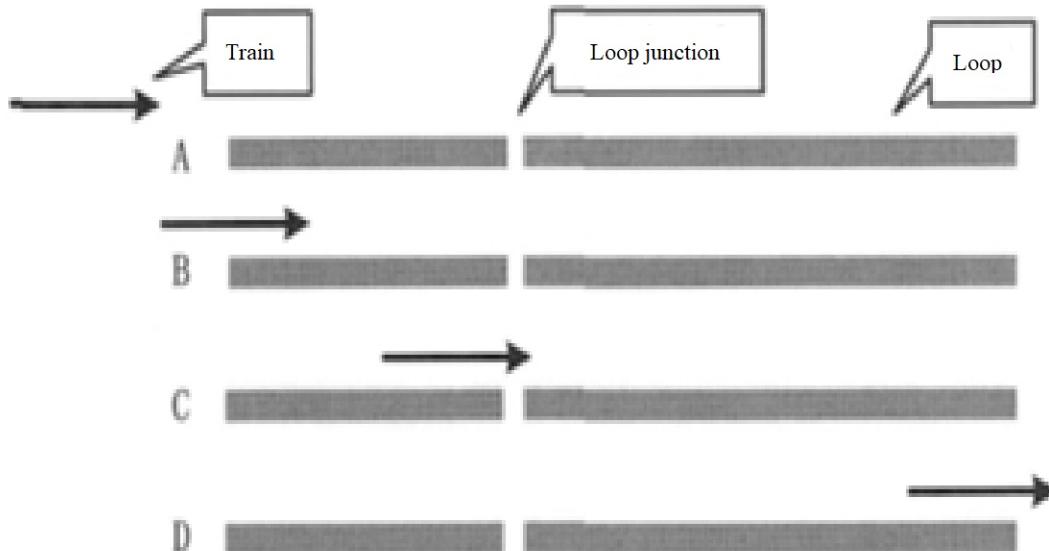


Figure 9 The driving situation

A state: The train does not enter the loop. The ATO loop identification module in the loop information demodulation device can determine that the ATO loop does not exist at the current position of the train, the processor controls the multiplexer based on the information, and inputs a signal transmitted by the standard signal source to 2FSK.

B state: The train enters the loop. The ATO identification circuit can determine that the current position of the train is on the ATO loop.

C state: The train crosses the intersection of the loop. When the train passes through the loop intersection, the signal amplitude of the loop information demodulating device is 0, and the phase locked loop in the 2FSK signal demodulating device is in an unlocked state.

D state: The train exits the loop. The ATO loop identification module can determine that there is no ATO loop at the current position of the train and repeat the A state after a sufficiently long time.

FSK modulation process

The CPU outputs the data information to the latch through the even address of the SRAM. Only one of the 8 -bit outputs of the latch is the data to be transmitted.

One of the bits generates a reset signal, clears the 12-bit binary counter, and recounts. The modulation process of the data information is shown in Figure 10.

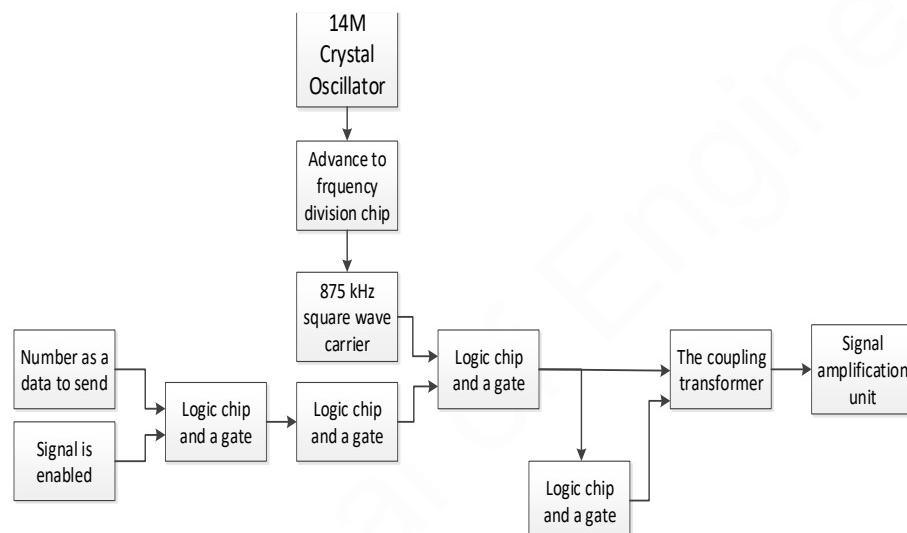


Figure 10 FSK modulation process

The square wave carrier of 875 kHz is obtained by dividing the 14M square wave pulse by frequency division and dividing by 16.

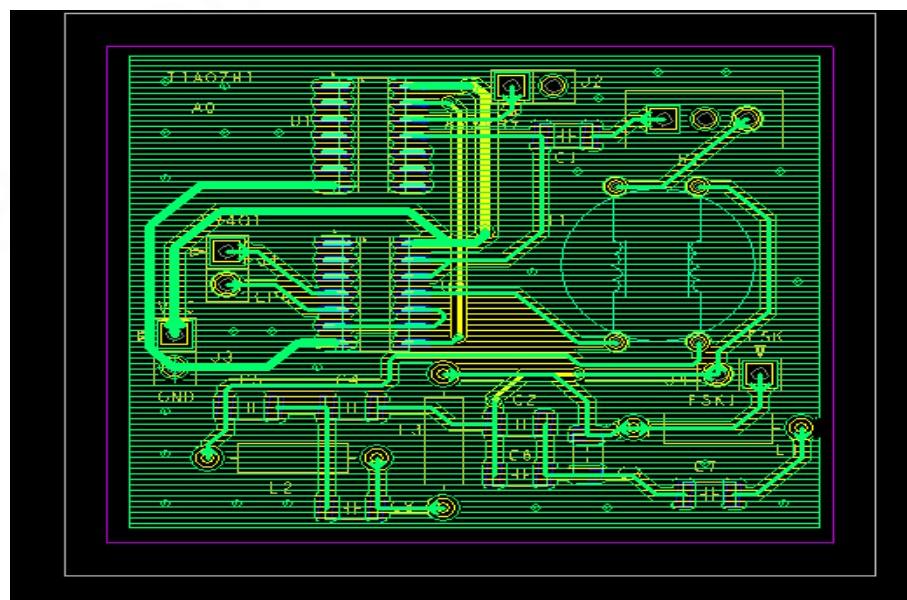


Figure 11 PCB diagram of modulation module

3. MODULATION MODULE

PCB Design Drawings

The PCB diagram of the modulation module is shown in Figure 11, and the physical diagram is shown in Figure 12. Due to the design of PCB with Cadence for the first time, the package of transformer is not well drawn, which can only be connected by flying wire when welding as shown in the figure 11.

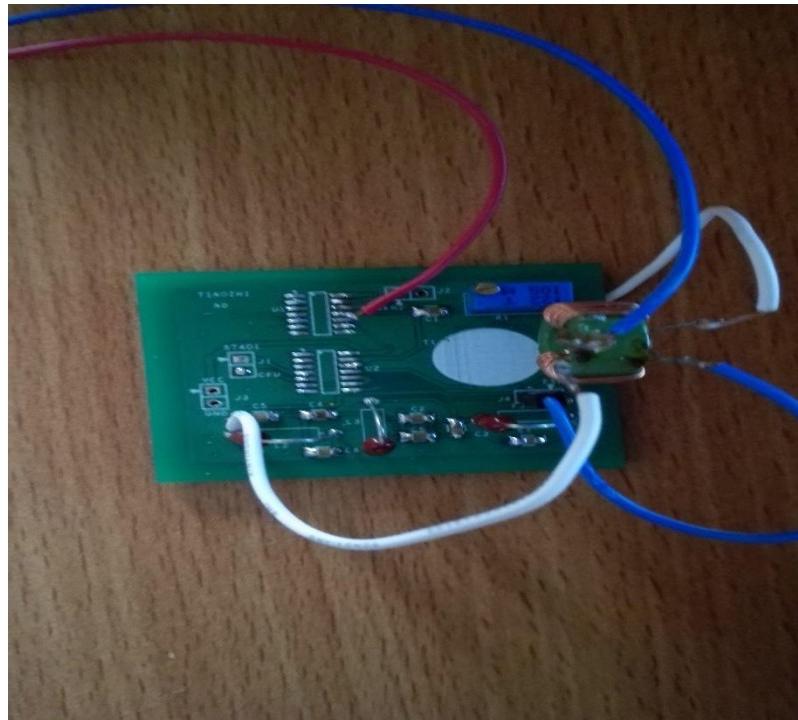


Figure 12 Physical object of modulation

The experimental program

The Cadence Allegro PCB Designer quickly takes simple and complex designs from concept to production in a constraint-driven design system to ensure functionality and manufacturability as shown in the figure13.

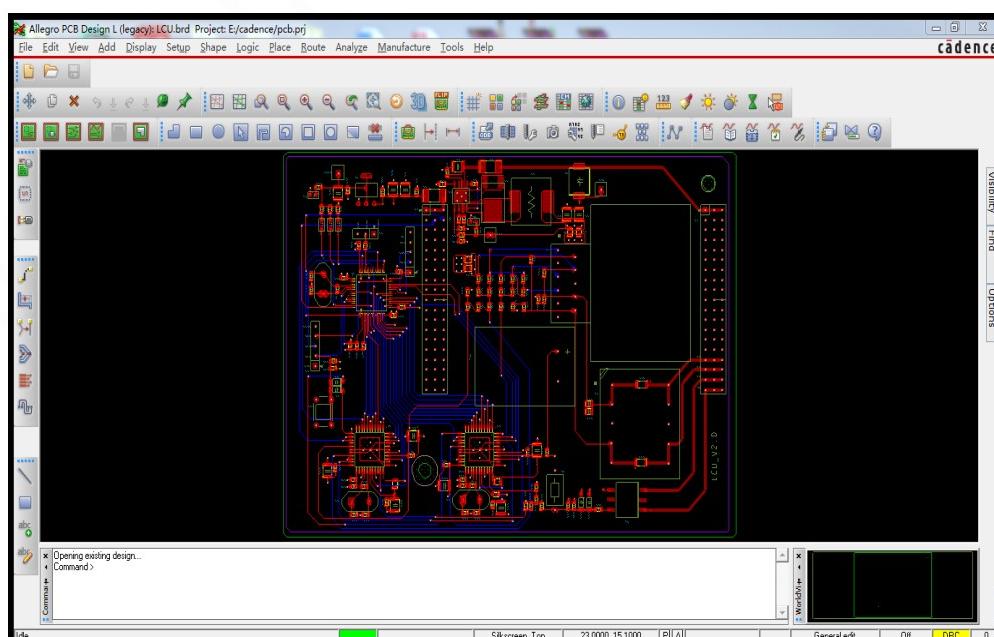


Figure 13 Cadence Allegro PCB Designer

The necessary equipment

The most important part of my project includes the utilization of hardware in order to show how the signal is received and transmitted. The PCB board LCU consists of ST7538 microcontroller with ARM Cortex as shown in the figures (14).

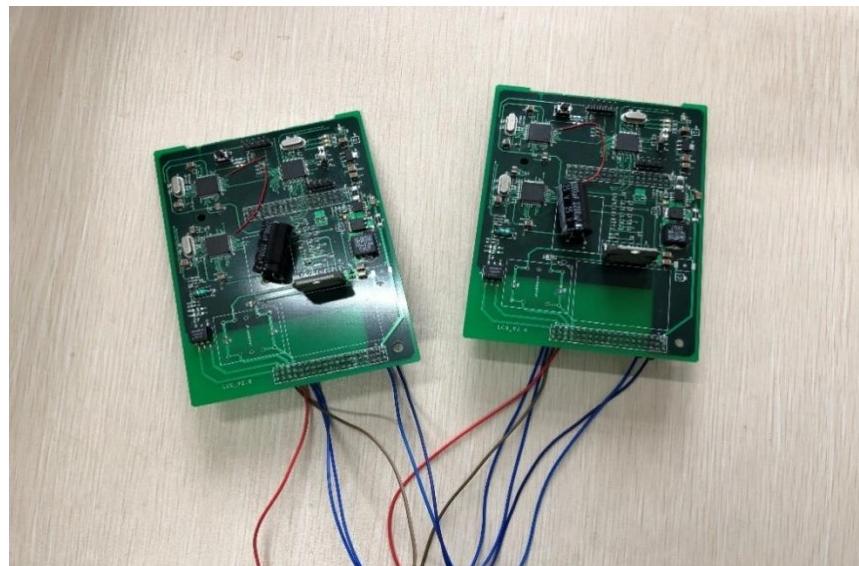


Figure 14 LCU and PCB

Train and wayside communication loop antenna technology

Electromagnetic Modeling of Antenna Coils

In order to establish the electromagnetic mode of the antenna coil, firstly, it is necessary to consider how to quantify the amount of gold acid in the solenoid, and the coil is inductive voltage at different positions of the cross induction loop to reasonably determine the size and shape of the solenoid antenna.

As shown in Figure 15, in order to facilitate calculations in the modeling, the long straight solenoid can be simplified into a series of multiple closed loop wires. For ease of calculation, the ground loop is considered to be an infinitely long conductor.

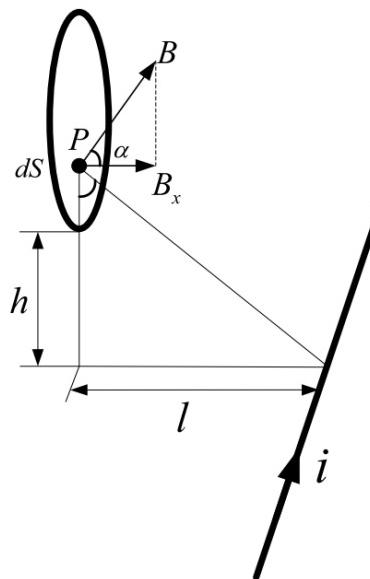


Figure 15 Simplified analysis model of solenoid coil

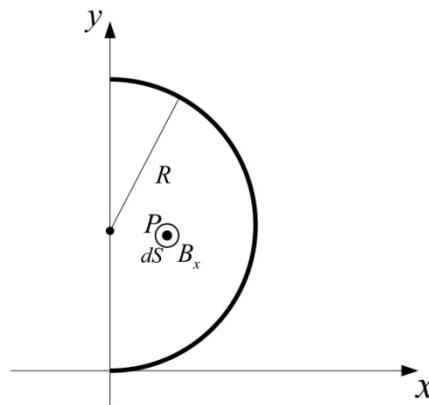


Figure 16 Solving the Solenoid Coil Magnetic Flux Model

When the heights of the excitation sources are same, the magnitude of the intensity of the electronic testimony excited by the excitation source on the long straight wire is same. As a spiral coil, the structure of the coil naturally exhibits a bilaterally symmetrical state, and therefore, the magnetic flux induced on the left and right sides of each coil is also same. It is for the above reasons that the coil can be simplified to a half model in the calculation of the coil, and only the magnetic flux in the half coil is calculated. Figure 15 shows the method of calculating the magnetic flux of the coil.

The above consensus needs to use the integral to solve the European stock, but its analytic solution is still difficult to obtain. Obtaining the effective expression of the relevant parameters by the formula can facilitate the analysis of the subsequent antenna coil model, so consider using the approximate approximation to simplify the formula as shown in Figure 16, which is the approximate approximation method like parsing ratio expressions.

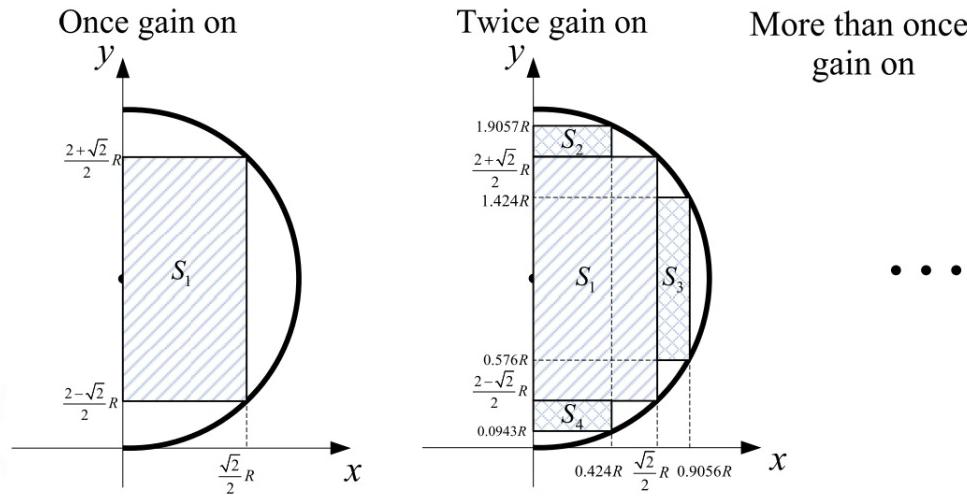


Figure 17 Rectangular Filling Approximation Algorithm

Antenna coil characteristics analysis

The physical picture of the laboratory antenna is shown in Figures 17. According to the model shown in Fig. 18, the distance between the coil and the ground loop is $h=15\text{cm}$, the permeability of the solenoid antenna, the amplitude of the sinusoidal current excited by the ground cable is $I=100\text{mA}$, and the signal frequency $f=40\text{kHz}$. The voltage signal strength of the electromagnetic field induced by the antenna coil is calculated by simulation when the horizontal distance between the excitation source and the antenna coil is 1. The simulation results are shown in Figure 19.



Figures 18 Antenna physical map

One board is installed on railway – wayside and is connected with the loop. The other one is installed on the train and it is connected with the antenna. When train passes it received sends signal to the antenna in the train. Wayside loop is like antenna.

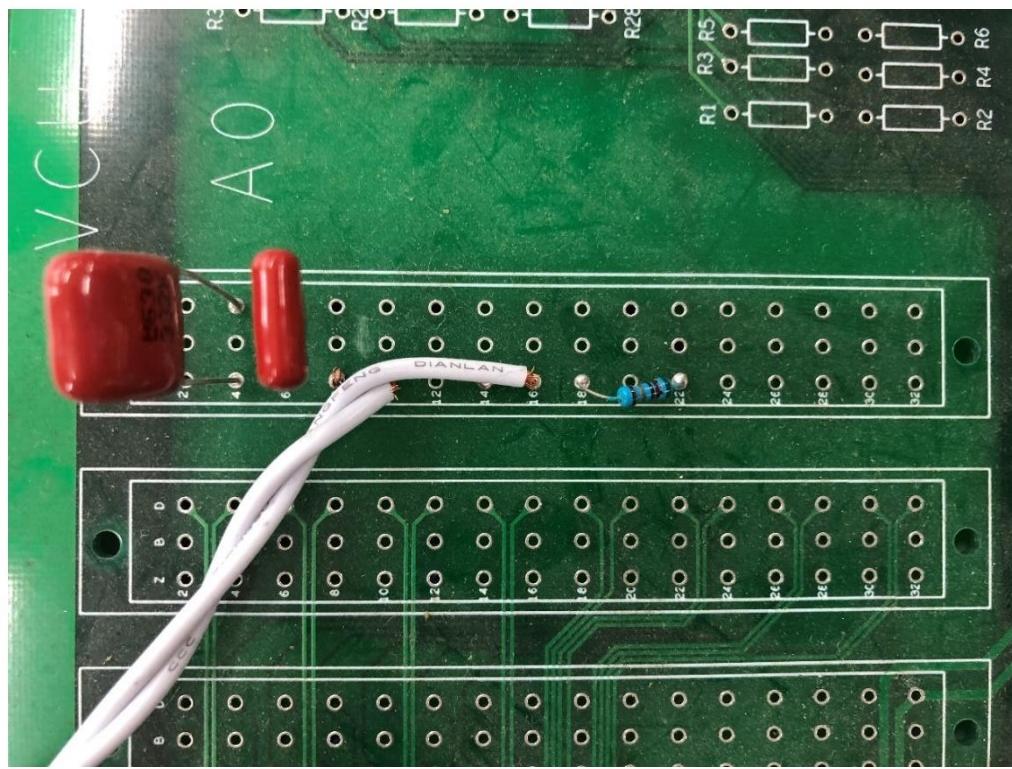


Figure 19 Antenna physical map

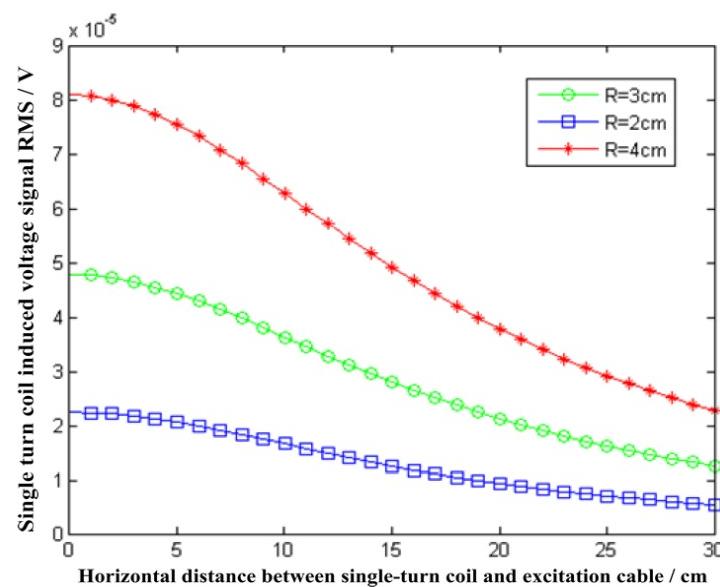


Figure 20 Voltage value induced when the radius of a single coil is 3cm, 2cm and 4cm

As shown in Table 1, the simulation is a list of parameters for the selected antenna coil. Through simulation, when the excitation source is changed from the horizontal distance of the antenna coil, the voltage amplitude of the electromagnetic signal induced by the excitation coil is fixed. The wire diameter of the coiled wire of the coil is fixed during simulation, and the number of turns of the antenna coil is changed. The simulation result is shown in Fig. 20.

Table 1 Antenna coil parameter values

parameter	Value	parameter	Value
Distance from the ground	h=15cm	Antenna permeability	
Excitation source current amplitude	I = 100mA	Induced signal frequency	f= 40kHz
Fixed antenna radius	R=3cm	Coil enameled wire diameter	d=0.8mm

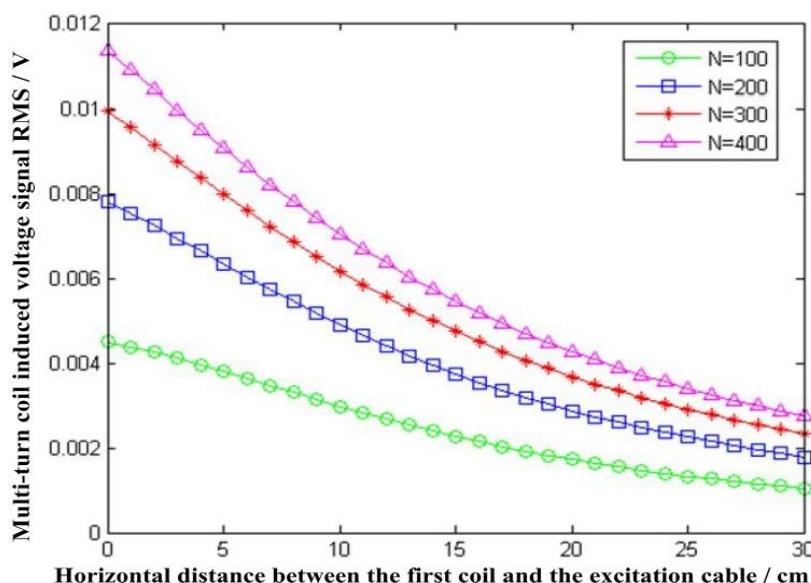


Figure 21 Induced voltage value when the number of turns of the solenoid coil is 100, 200, 300 and 400

As shown in Table 2, the simulation is a list of parameters of the selected antenna coil. Through simulation, when the excitation source is changed from the horizontal distance of the antenna coil, the voltage amplitude of the electromagnetic signal induced by the antenna coil is fixed. The number of turns of the antenna coil is fixed during the simulation, and the wire diameter of the coil enameled wire is changed. The simulation result is shown in Figure 21.

Table 2 Antenna coil parameter values

parameter	Value	parameter	Value
Distance from the ground	$h=15\text{cm}$	Antenna permeability	
Excitation source current amplitude	$I = 100\text{mA}$	Induced signal frequency	$f = 40\text{kHz}$
Fixed antenna radius	$R=3\text{cm}$	Antenna coil	300N

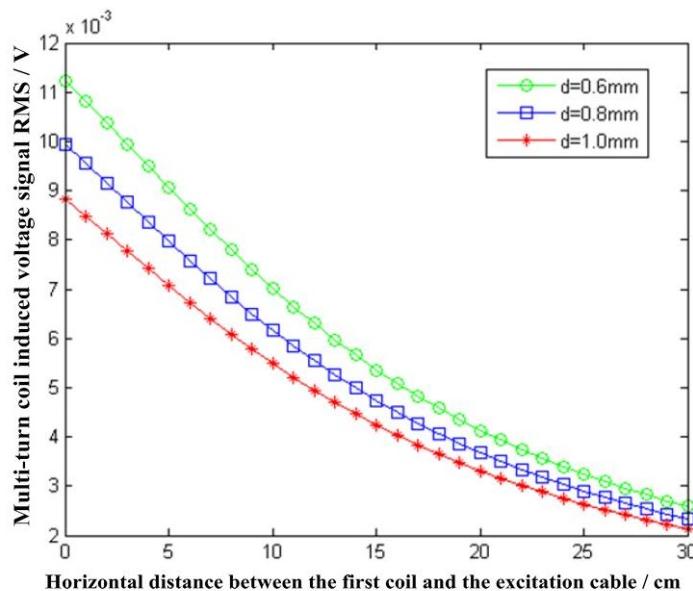


Figure 22 Induced voltage value when the solenoid coil diameter is 0.5mm, 0.8mm or 1.0mm

By analyzing Figure 22, it can be found that the strength of the voltage signal induced by the antenna coil is closely related to the radius of the coil. When the radius of the antenna coil increases, the strength of the voltage signal induced by the antenna coil increases. Figure 23 shows that the direct relationship between the strength of the voltage signal sensed by the antenna coil and the antenna coil radius is not linear, but also varies with the radius of the antenna coil. As shown in Figure 23, when the size of the antenna coil is small, that is, less than 30 cm, the sensitivity of the voltage signal received by the antenna coil is the highest. On the other hand, it can be found that the intensity of the induced voltage signal of the antenna coil is also related to the number of solenoid turns of the antenna coil. The larger the number of turns of the coil, the stronger the voltage signal that the antenna can sense. However, in the design of the antenna, the number of turns of the antenna coil cannot be increased blindly, because the increase in the number of turns of the coil inevitably causes an increase in the length of the antenna coil. When the length is too long, the sensitivity of the signal that the antenna coil can sense is also changed, and will gradually become smaller. When the number of turns of the antenna coil is 300N and 400N, the sensitivity of the entire coil receiving signals is substantially the same at this time.

In practical applications, in order to effectively reduce the equivalent capacitance value that may be caused by the voltage difference between the antenna layers, it is necessary to carefully perform a layer winding on the outer surface of the solenoid antenna with an enameled wire. If the number of turns of the antenna coil is determined first, the coil radius of the wrapped enameled wire is narrower, the length of the solenoid antenna will be shorter, which will result in the closer the distance of the entire coil from the excitation loop. In other words, the narrower the diameter of the enameled wire, the stronger the intensity of the signal received by the antenna coil. In addition, it is also necessary to consider the influence of some other effects on the antenna, such as the skin effect, so diameter of the enameled wire cannot be too small, and the narrower diameter allows smaller circuit to flow.

4. EXPERIMENTAL DATA ANALYSIS

On the physical basis of the laboratory antenna model, the upper computer software is shown in Figure 24, through the upper machine A analog ground control center to send a message in line with the communication frame format, the upper machine B analog car host receives the message. Each message is sent at a fixed value and is continuously monitored to test the stability of the system.



Figure 23 Upper machine simulation interface

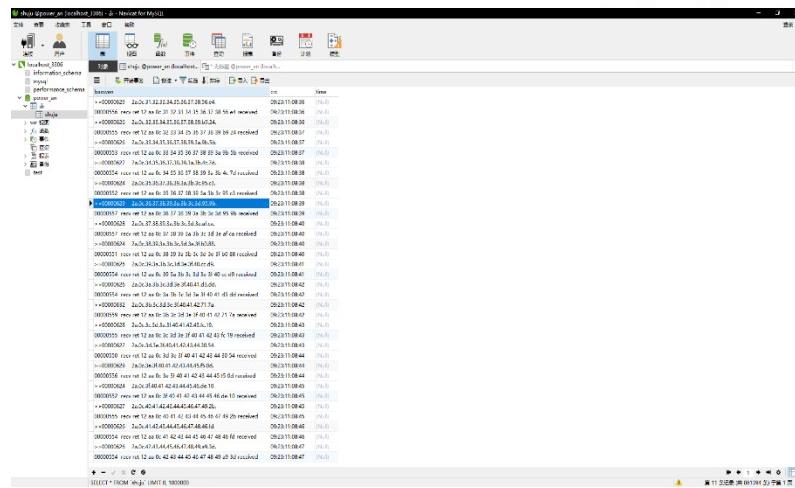


Figure 24 Navicat for MySQL Data Monitoring Interface

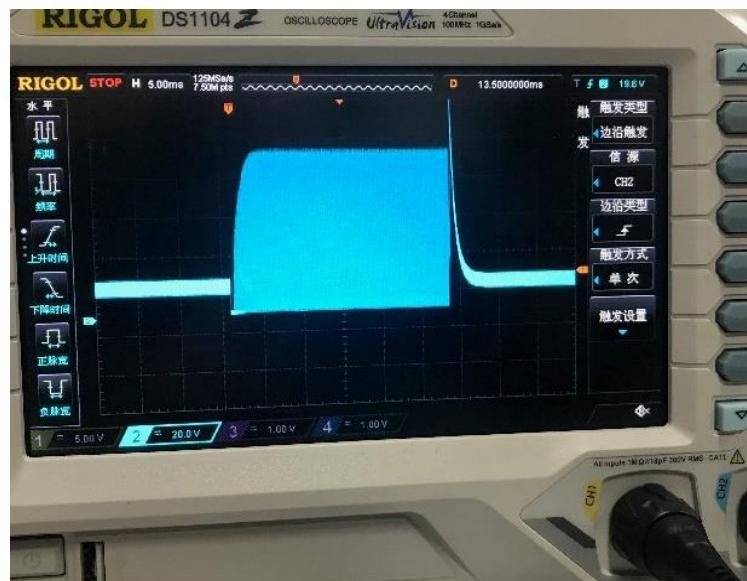


Figure 25 Texas Instruments tool

The message sent in real time using Navicat for MySQL monitoring and storage of the upper computer is shown in Figure 25. The experimental data will be analyzed to detect the stability of the system.

Texas instruments testing device is used for detection of transmitting signal waveform. The results obtained after continuous testing were summarized, the amount of data sent and received by the message was 2,000,000, and the data packet 2, as shown in Figure 26, the system was achieved with a loss rate of 10-6 under laboratory conditions.

	A	B
1	>>>00000627 2a.0c.9a.9b.9c.9d.9e.9f.40.41.82.2a.	07:23:09:47:33
2	00000558 recv ret 12 aa 0c 9a 9b 9c 9d 9e 9f 40 41 82 2a received	07:23:09:47:33
3	>>>00000631 2a.0c.9b.9c.9d.9e.9f.40.41.82.26.4b.	07:23:09:47:33
4	>>>00000659 recv ret 12 aa 0c 9b 9c 9d 9e 9f 40 41 82 26 4b received	07:23:09:47:34
5	>>>00000621 2a.0c.9c.9d.9e.9f.40.41.82.43.b2.2f.	07:23:09:47:34
6	00000550 recv ret 12 aa 0c 9c 9d 9e 9f 40 41 82 43 bd.2f received	07:23:09:47:34
7	>>>00000625 2a.0c.9d.9e.9f.40.41.82.43.e4.b0.40.	07:23:09:47:35
8	00000553 recv ret 12 aa 0c 9d 9e 9f 40 41 82 43 e4 b0 40 received	07:23:09:47:35
9	>>>00000626 2a.0c.9e.9f.40.41.82.43.e4.45.77.48.	07:23:09:47:35
0	00000554 recv ret 12 aa 0e 9e 9f 40 41 82 43 e4 45 77 48 received	07:23:09:47:36
1	>>>00000630 2a.0e.9f.40.41.82.43.e4.45.46.9b.23.	07:23:09:47:36
2	00000558 recv ret 12 aa 0e 9f 40 41 82 43 e4 45 46 9b d3 received	07:23:09:47:36
3	>>>00000624 2a.0e.40.41.82.43.e4.45.46.47.69.19.	07:23:09:47:37
4	00000552 recv ret 12 aa 0e 40 41 82 43 e4 45 46 47 69 19 received	07:23:09:47:37
5	>>>00000626 2a.0e.41.82.43.e4.45.46.47.48.66.ef.	07:23:09:47:37
6	00000554 recv ret 12 aa 0e 41 42 43 e4 45 46 47 48 66 ef received	07:23:09:47:37
7	>>>00000630 2a.0e.42.43.e4.45.46.47.48.69.0f.	07:23:09:47:38
8	00000559 recv ret 12 aa 0e 42 43 e4 45 46 47 48 69 0f received	07:23:09:47:38
9	>>>00000621 2a.0e.43.e4.45.46.47.48.69.aa.bb.70.	07:23:09:47:39
0	00000549 recv ret 12 aa 0e 43 e4 45 46 47 48 69 aa bb 70 received	07:23:09:47:39
1	>>>00000629 2a.0e.44.e5.46.47.48.69.aa.bb.7c.56.	07:23:09:47:39
2	00000558 recv ret 12 aa 0e 44 e5 46 47 48 69 aa bb 7c 56 received	07:23:09:47:39
3	>>>00000624 2a.0e.45.46.47.48.69.aa.bb.e5.68.	07:23:09:47:40
4	00000552 recv ret 12 aa 0e 45 46 47 48 69 aa bb ee 45 e8 received	07:23:09:47:40
5	>>>00000629 2a.0e.46.47.48.69.aa.bb.ee.ad.45.60.	07:23:09:47:41
6	00000557 recv ret 12 aa 0e 46 47 48 69 aa bb ee ad 45 b0 received	07:23:09:47:41
7	>>>00000624 2a.0e.47.48.69.aa.bb.ad.ee.9f.e1.	07:23:09:47:41
8	00000552 recv ret 12 aa 0e 47 48 69 aa bb ad ee 9f e1 received	07:23:09:47:41
9	>>>00000629 2a.0e.48.49.aa.bb.ad.ee.80.a3.	07:23:09:47:42
0	00000556 recv ret 12 aa 0e 48 49 aa bb ad ee af 80 a3 received	07:23:09:47:42
1	>>>00000628 2a.0e.49.aa.bb.ad.ee.af.b0.9f.f4.	07:23:09:47:42
2	00000556 recv ret 12 aa 0e 49 aa bb ad ee af b0 9f f4 received	07:23:09:47:43
3	>>>00000626 2a.0e.aa.bb.ac.ad.ee.af.b0.b1.e5.	07:23:09:47:43
4	00000555 recv ret 12 aa 0e aa bb ac ad ee af b0 b1 e5 received	07:23:09:47:43
5	>>>00000624 2a.0e.ab.ac.ad.ee.af.b0.b1.b2.42.4f.	07:23:09:47:44
6	00000553 recv ret 12 aa 0e ab ac ad ee af b0 b1 b2 42 4f received	07:23:09:47:44
7	>>>00000630 2a.0e.ac.ad.ee.af.b0.b1.b2.b3.56.e8.	07:23:09:47:44
8	00000558 recv ret 12 aa 0e ac ad ee af b0 b1 b2 b3 56 e8 received	07:23:09:47:45
9	>>>00000626 2a.0e.ad.ee.af.b0.b1.b2.b3.b4.36.	07:23:09:47:45
0	00000553 recv ret 12 aa 0e ad ee af b0 b1 b2 b3 b4 36 received	07:23:09:47:45

Figure 26 Message Data Summary

5. CONCLUSION

In order to able to control the train, including real-time control of key participation such as speed, position and distance, a wireless communication system between the wireless vehicles must be established. The train control system is built on the vehicle wireless communication technology, and can effectively improve the running efficiency of the train and improve the safety of train operation. The cornerstone of the train control system is the vehicle-to-ground communication system, which is a vital component of the train control system. Information is communicated between the entire vehicle-mounted-system when the information is communicated between the ground control equipment and the on-board communication equipment on the train. The only way is to exchange.

This dissertation takes the vehicle-to-ground communication system and key technologies as the research object, and focuses on the loop control technology between the vehicle and the ground communication, and the key technology of the antenna between the vehicle and the ground communication. This thesis first introduces the research background and significance of the subject, and summarizes the current research status and results at home and abroad. Then this work analyzes the vehicle wireless communication system and its related design in detail. This thesis first analyzes the train control system, and then introduces the basic structure of the vehicle-to-ground communication system and the working principle between the vehicle and the ground communication. It introduces several different ways of vehicle-to-ground information transmission, and gives the vehicle-ground wireless communication. On this basis, we study and analyze the design problem of the vehicle-to-ground wireless communication system. We introduce the induction loop technology and the positioning speed measurement system, and then focus on the design of the vehicle-ground loop communication system. In this work, the FSK signal modulation technology is also studied and analyzed in detail, focusing on the acceptance rate loop information, principle and the application mode of FSK wireless signal demodulation technology. Finally, this dissertation analyzes and studies the vehicle-ground communication loop antenna technology, and also the electromagnetic model and characteristics of the antenna.

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REFERENCE

1. Jiang Hailin, Wang Hongwei, Qi Chunhai, Tang Tao. Analysis of Communication Capacity of Urban Rail Transit Vehicles[J]. Journal of the China Railway Society, 2014, 08: 44-48.
2. Martinez-Ros, Alejandro Javier, José Luis Gomez-Tornero, and George Goussetis. "Planar leaky-wave antenna with flexible control of the complex propagation constant." IEEE Transactions on Antennas and Propagation 60.3 (2011)
3. Jia-yi, L. I. "Analysis of Interference in Wireless Technology between Passenger Information System and Communication Based Train Control System in Subway [J]." Journal of Railway Engineering Society 6 (2011).
4. Xu Lin. Research and implementation of short-range wireless communication technology [D]. Nanjing: Nanjing University of Science and Technology, 2003.
5. Jaradat, Toleen, et al. "Energy efficient cross-layer routing protocol in wireless sensor networks based on fuzzy logic." 2013 9th International Wireless Communications and Mobile Computing Conference (IWCMC).IEEE, 2013.
6. Shang Xinghong. Research on some key technologies of wireless sensor networks [D]. Nanjing: Nanjing University of Science and Technology, 2013.
7. Yu, Jiguo, et al. "A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution." AEU-International Journal of Electronics and Communications 66.1 (2012):
8. Zhang, Junguo, et al. "The NS2-based simulation and research on wireless sensor network route protocol." 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing. IEEE, 2009.
9. Hailing, Cui Li Ju, et al. "Overview of Wireless Sensor Networks [J]." Journal of Computer Research and Development 1 (2005): 021.
10. Korkalainen, Marko, et al. "Survey of wireless sensor networks simulation tools for demanding applications." 2009 Fifth international conference on networking and services. IEEE, 2009.
11. Zhang, Xiaodong, Xiujuan Li, and Jie Zhang. "Design and implementation of embedded monitoring system for grain storage." 2010 2nd IEEE International Conference on Information Management and Engineering. IEEE, 2010.
12. Zhou Liang. Research on wireless sensor network location and tracking tech. [D]. Chengdu: University of Electronic Science and Technology, 2014.
13. XuJian, Yang Shanshan. Design of ZigBee Coordinator Node Based on CC2530[J]. Internet of Things Technology, 2012, 05: 55-57.
14. Li Yuezong. Research on train group operation optimization based on CBTC- MAS [D]. Chengdu: Southwest Jiaotong University, 2014.
15. Wan Xiaoqiang. Research on Enhanced Train Control System Based on Wireless Communication in Qinghai-Tibet Railway [D]. Chengdu: Southwest Jiaotong University, 2006.
16. Alcatel enters Wuhan Light Rail by reducing profits [J]. Urban Rail Transit Research, 2004, 05: 8.
17. Li, Xin, and Hui Lu. "Hardware Platform Design of Radio Compass Automatic Test System [J]." Computer Engineering3 (2007).
18. Zhang, Peng, ZhenhuaDuan, and Cong Tian. "Simulation of CTCS-3 protocol with temporal logic programming." Proceedings of the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD).IEEE, 2013.